Final Report

Time Neutron Technique for UXO Discrimination

SERDP Project MR-1635

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In response to the Strategic Environmental Research and Development Programs (SERDPs) SON Number MMSON-08-04, Science Applications International Corporation (SAIC) was funded to evaluate a neutron-based, non-intrusive inspection technique called Associated Particle Imaging (API) for use as a man-portable sensor that discriminates the fill of unexploded ordnance (UXO) found on the ground surface or partially buried. The goal is to have a sensor weighing less than 80 pounds (35 kilograms) that can be carried or wheeled into place and provide identification of the munitions fill within a few minutes. The objectives of this project were to conduct experiments with a lab-based system to determine the performance capability of API, including the probability of detection and false alarm. Based on these results, a concept design and plan forward were developed.

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ABSTRACT

In response to the Strategic Environmental Research and Development Program's (SERDP's) SON Number MMSON-08-04, Science Applications International Corporation (SAIC) was funded to evaluate a neutron-based, non-intrusive inspection technique called Associated Particle Imaging (API) for use as a man-portable sensor that discriminates the fill of unexploded ordnance (UXO) found on the ground surface or partially buried. The goal is to have a sensor weighing less than 80 pounds (35 kilograms) that can be carried or wheeled into place and provide identification of the munitions fill within a few minutes. The objectives of this project were to conduct experiments with a lab-based system to determine the performance capability of API, including the probability of detection and false alarm. Based on these results, a concept design and plan forward were developed.

Monoenergetic 14 MeV neutrons are emitted from a small electronic generator that employs the deuteron-tritium nuclear reaction. An alpha particle is emitted directly opposite to the neutron. In the API technique, the alpha particle is detected using a position-sensitive detector so the direction of the outgoing neutron is known. An outgoing neutron that interacts in the target volume can produce gamma rays, the energy of which is measured by nearby detectors. By using the time of flight between detection of the alpha particle and the gamma ray, the location of the neutron reaction is known. The gamma ray spectra are analyzed for each voxel to determine the amount of carbon, oxygen, and nitrogen in the target volume and, therefore, the material present. Because of the "electronic collimation" of the neutrons, the background from surrounding material is greatly reduced, leading to improved performance compared to other non-API-based neutron sensors. Furthermore, a separate background measurement is not required, reducing overall inspection time.

SAIC and Western Kentucky University initially conducted trade studies of various gamma ray and alpha particle detectors and high-speed electronics for use with a lab system. The API generator would be leased from its manufacturer and integrated into a lab system for the testing. SAIC later teamed with Applied Signal Technology, Inc., which provided a modified version of their API-based neu-VISION™ system used for explosives detection in vehicles. A number of experiments were conducted on a set of simulated UXO targets with inert and simulated explosives fills. Because of the lower output of the API neutron generator, only a subset of the desired measurements was made. However, the performance was good, with a probability of detection of 83% and a probability of false alarm of 3%. The performance and inspection time are expected to greatly improve with a stable, high-output API generator.

The portable API system could be used during remediation efforts to quickly and safely identify UXO fills and separate explosives from inerts. The cost savings is significant compared to efforts where each of the munitions is assumed to be an explosive, leading to expensive excavation efforts. Based upon the results of the experiments, a concept design of a man-portable system was produced.

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ACRONYMS

ANFO	Ammonium Nitrate- Fuel Oil mixture
API	Associated Particle Imaging
AST	Applied Signal Technology, Inc. (Lab in Torrance, CA)
AT	Anti-tank
BGO	Bismuth germinate $Bi_3Ge_4O_{12}$
BIP	Blow-in-Place
COMP B	A mixture of TNT and RDX
C-4	Composition 4 military plastic explosive
CFD	Constant Fraction Discriminator
Cps	counts per second
CsI	inorganic scintillator crystal
CW	Chemical Warfare agent
d-T	deuterium-tritium
DoD	Department of Defense
DOE	Department of Energy
ECC	Environmental Chemical Corporation
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FWHM	Full Width (at) Half Maximum
GFE	Government-Furnished Equipment
HE	High Explosive
HPGe	High Purity Germanium
IEDs	Improvised explosive devices
$LaBr_3$	Lanthanum Bromide Crystal Detector
LS	Least Squares spectral analysis
MCNP	Monte Carlo N-Particle code
MMRP	Military Munitions Response Program
MRA	Munitions Response Area
MRS	Munitions Response Site
NaI	Sodium Iodide
NAVEODTECHDIV	Navy Explosive Ordnance Disposal Technology Division, Indian Head, MD
NFI	Non-invasive Filler Identifier (program sponsored by NAVEODTECHDIV)
NG	Neutron generator
NIM	Nuclear Instrument Module
Pdet or Pd	Probability of Detection
Pdfs	Probability Density Functions
PET	Positron Emission Tomography
Pfa	Probability of False Alarm
PFTNA	Pulsed Fast/Thermal Neutron Analysis
PMTs	Photomultiplier tubes
POP	Plaster of Paris
RDX	Cyclonite (originally known as Royal Dutch Explosives)
ROI	Region of Interest
SAIC	Science Applications International Corporation
SEC	Spider Elemental Counts
SERDP	Strategic Environmental Research and Development Program
SNR	Signal to noise ratio
SPIDER	SPectrum Interpolation and DEconvolution Routine
TAC	Timing to Amplitude Converter
TNA	Thermal neutron analysis
TNT	Trinitrotoluene
UXO	Unexploded Ordnance
WKU	Western Kentucky University

ACKNOWLEDGEMENTS

SAIC wishes to acknowledge the major contributions of David Penn and his team at Applied Signal Technology, Inc., who provided an associated particle system for testing and conducted measurements with the simulated UXO targets. SAIC would like to acknowledge the important contributions of Alex Barzilov, Ph.D., and his team at Western Kentucky University for conducting timing and energy resolution testing of gamma ray detectors. SAIC would also like to thank Thomas Douglas of the Navy's Explosive Ordnance Disposal Technology Division in Indian Head, Md., for general oversight and guidance. SAIC wishes to express its appreciation to SERDP for funding and supporting this project for UXO discrimination efforts.

1 OBJECTIVE

This project addressed SERDP's SON Number MMSON-08-04: Advanced Technologies for Detection, Discrimination and Remediation of Military Munitions in SERDP's FY08 Broad Agency Announcement released on November 2006. SAIC's objective was to evaluate a neutron-based, non-intrusive inspection technique called Associated Particle Imaging (API) for use as a man-portable sensor that discriminates the fill of unexploded ordnance (UXO) found on the ground surface or partially buried. The goal is to have a sensor weighing less than 80 lbs (35 kg) that can be carried or wheeled into place and provide identification of the munitions fill within a few minutes. The objectives of this project were to conduct experiments with a lab-based system to determine the performance capability of API, including the probability of detection and false alarm. Based on these results, a concept design and plan forward were developed.

2 BACKGROUND

Prior to the selection of a disposal method for UXO, a determination must be made of the ordnance type (rocket, mortar, projectile, etc.) and what filler material it contains (inert or empty), practice, HE, illumination, chemical (i.e., smoke), chemical agent (CW). The materials can range from standard military explosives to chemical agents to inert simulants. Currently, trained UXO experts perform this determination using external markings and visual examination. Many times the UXO has weathered or corroded and the markings and external visual cues are deteriorated or absent. If a positive determination cannot be made that the UXO is free of explosives or chemicals, all questionable UXO are required to be treated as explosive- or chemical-filled, so the cost of clearance and disposal operations is greatly increased. If a less conservative approach is used, accidents occur, such as those at the Naval Surface Warfare Center, Indian Head Division, and the San Clemente Test Range, that lead to injury or loss of life. There is the need for a means of quickly and accurately determining the fill of UXO to permit the rapid disposition of inert or empty rounds and proper handling of explosive- or chemical-filled UXO.

The Naval Explosive Ordnance Technology Division (NAVEODTECHDIV) has been investigating the use of the Pulsed ELemental Analysis with Neutrons (PELAN) developed by the University of Western Kentucky (WKU) and SAIC for discrimination of UXO, and previously SERDP[1] and ESTCP[2] have supported projects to improve on PELAN performance. These efforts have demonstrated the utility of using PELAN to gather data from explosive, chemical- and inert-filled UXO and have highlighted the need for more advanced signal processing to increase the probability of detection and reduce the false alarm rate.

The project tasks were to build a lab system and conduct tests with simulated UXO targets to evaluate the API technique for the classification of UXO filler at cleanup sites. The goals of these improvements are to increase the filler detection efficiency and accuracy, and reduce false alarm rates, which, in turn, would reduce the overall cost of UXO remediation.

3 MATERIALS AND METHODS

3.1 Technical Description

High explosives (TNT, RDX, C-4, etc.) are composed primarily of the chemical elements hydrogen (H), carbon (C), nitrogen (N), and oxygen (O). Many innocuous materials are also primarily composed of these same elements. Though nitrogen is a key signature of explosives, these elements are found in many materials with very different elemental ratios and concentrations. For example, narcotics have a C/O ratio that is at least a factor of two larger than the innocuous materials. Explosives have been shown to be differentiated by utilization of both the C/O ratio and the C/N ratio. The problem of identifying explosives and other threat materials is thus reduced to the problem of elemental identification.

Nuclear techniques present a number of advantages for non-destructive elemental characterization. These advantages include the ability to examine bulk quantities with speed, high elemental specificity, and no memory effects from the previously measured object. These qualities are important for an effective detection system for explosives.

Neutrons are highly penetrating particles, so their intensity is not diminished significantly by the thickness of commonly utilized containers. Furthermore, the outgoing gamma rays are also very penetrating, easily exiting the interrogated volume. Thus, the method is non-intrusive (the interrogation can take place from a distance of several inches) and non-destructive because of the very small amount of radiation absorbed by the interrogated object.

3.2 The PELAN System

Developed by Western Kentucky University (WKU) with support from NAVEODTECHDIV and other U.S. government agencies, PELAN utilizes a pulsing deuterium-tritium (d-T) neutron generator. By using fast neutron reactions, capture reactions, and activation analysis, a large number of elements can be identified in a continuous mode without sampling. PELAN is a man-portable device designed for portability and rapid deployment. This system, shown in Figure 1, consists of two equal weight portions. The upper section is the neutron generator and accompanying digital control system. The lower section contains the embedded computer, detector system, detector shielding, and operator interfaces such as an Ethernet communication link to a laptop. The controller provides fully automatic operation of PELAN. Through a user-friendly graphical user interface (GUI), all necessary power supplies are energized, neutrons are produced, and data is collected for a predetermined time. Upon the completion of data acquisition, the data are automatically reduced, analyzed, and the results of the interrogation are displayed on the screen.

SAIC has an exclusive license with Numat, Inc., and WKU to build and sell PELAN systems. Earlier PELAN prototype systems and the latest PELAN IV have been tested and demonstrated at NAVEODTECHDIV in Indian Head, Md. Over a two-year period, PELAN was used to acquire over 500 measurements at Indian Head on a variety of shells on a number of different soil types.

Figure 1 The PELAN IV system.

3.3 The API Technique

The API technique is a neutron-based technology. Its method is illustrated in Figure 2. As in PELAN, neutrons are created by a compact, commercial neutron generator using the d+T reaction. Neutrons are always created in coincidence with an associated alpha particle that travels in the opposite direction to the neutron. The coincident alpha particle is used to determine the direction of the neutron so the time of creation and trajectory are determined. The emitted neutron interacts with material in the interrogation volume and generates gamma rays from inelastic neutron scattering with the target nuclei.

The resulting gamma ray energy is measured along with the time that it arrived. The neutron trajectory, time of creation and gamma ray time stamps are used to determine the location where the gamma ray was created by the time-of-flight method. In the analysis, gamma spectra are assembled for three-dimensional (3-D) regions of space (voxels), and these voxels are analyzed for elemental gamma signatures to determine their material composition.

The main advantage of using the API technique for UXO discrimination is that it improves the signal-to-noise ratio (SNR) by effectively collimating the beam because the origin of the neutron-target reaction is known. This reduces the background significantly, by up to a factor of 10 times. Furthermore, the API method allows one to observe the material behind or to the side of the shell, providing background gamma information for the data analysis. This last advantage eliminates the need for taking a separate background as typically needed for PELAN, thus reducing time and improving the reliability of the analysis.

For evaluating the API technique, SAIC teamed with AST, which has developed a vehicle bomb inspection sensor system called neu-VISION™ employing the API approach (see www.appsig.com for details). AST has received ongoing support by the U.S. government for developing this system to detect explosives in cars. The neu-VISION system uses the Thermo

Scientific API 120 neutron generator and 16 LaBr detectors to inspect and identify suspect targets in the vehicles. For testing in this project, AST modified their system so it represented the geometry of a portable system, with two LaBr detectors and the Thermo API 120 neutron generator placed over a box filled with soil. More details of the experimental setup are provided below.

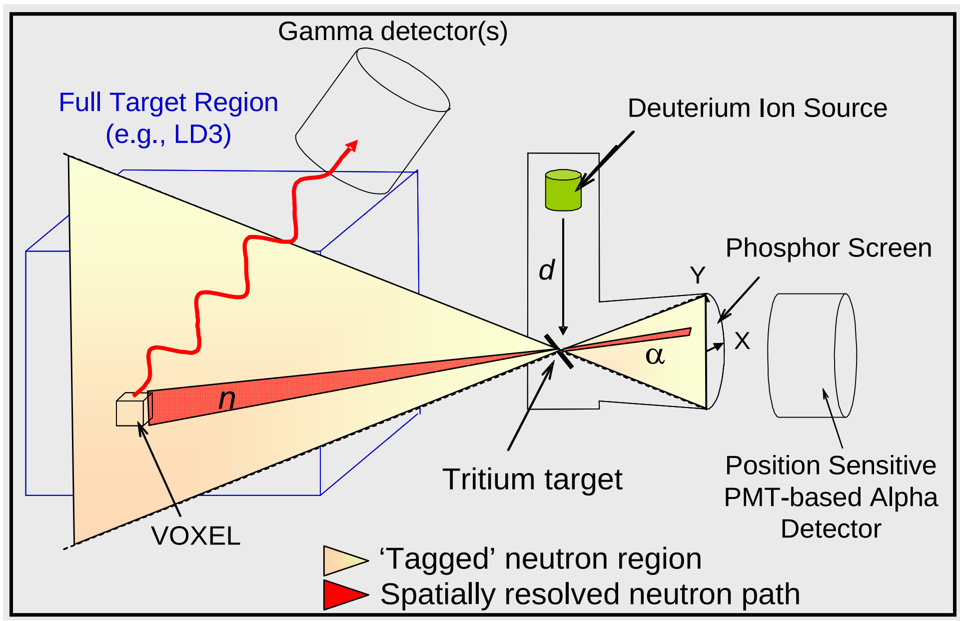

Figure 2 The associated particle imaging technique.

4 RESULTS AND DISCUSSION

4.1 Fast Electronics Evaluation

The original approach of this project was to lease an API 120 neutron generator from Thermo and use available electronics to assemble and test a lab model. For this lab model, WKU and SAIC conducted an evaluation of high-speed PMTs and electronics for the alpha particle detector and the alpha-gamma coincidence electronics.

The following tasks were conducted during the first half of the project.

- Coincidence timing resolution studies with various scintillators (LaBr, BGO, CsI) and PMTs; used standard NIM electronics (CFD, TAC, etc.)
- Survey of high-speed PMTs (Hamamatsu Photonics R2083, R9779) for alpha detection
- Survey of high-speed digital coincidence electronics (Becker & Hickl GmbH, C.A.E.N. SPA, XIA LLC, Struck Innovative Systeme GmbH)

Photos of the timing resolution testing with the 3”x3” LaBr (purchased from Saint Gobain) and 3”x3” BGO detectors are shown in Figures 3 and 4, respectively. A timing-to-amplitude histogram is shown for the LaBr detector in Figure 5 and indicates a timing resolution of about 1.5 ns (FWHM).

Figure 3 The Saint Gobain 3"x3" LaBr detector (foreground) in a timing response measurement.

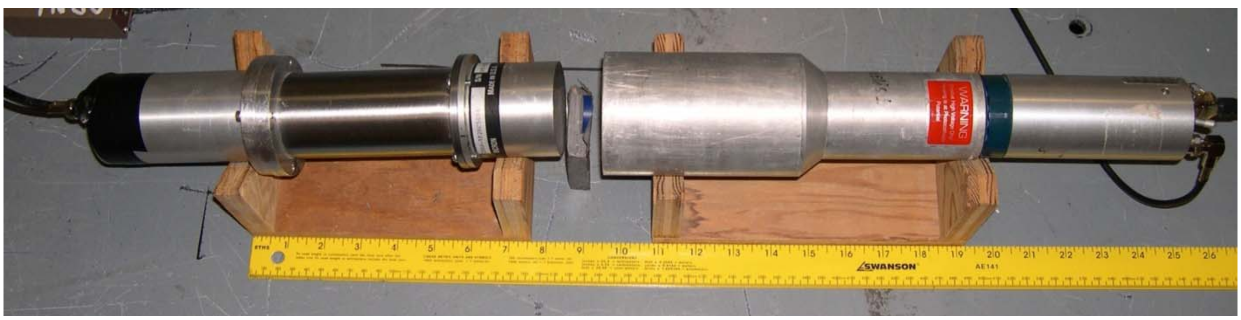

Figure 4 The 3"x3" BGO detector (right) timing response measurement.

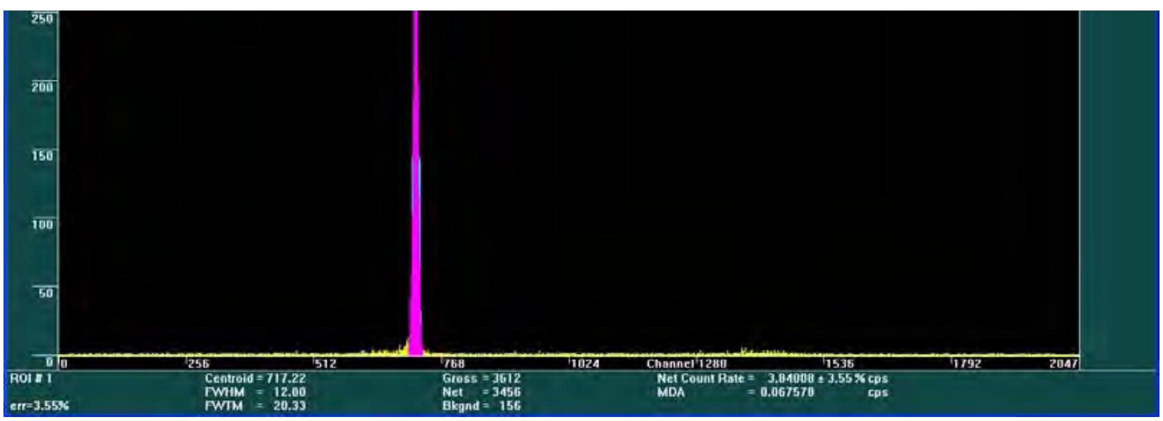

Figure 5 Example timing to amplitude histogram of LaBr showing resolution of ~1.5 ns (FWHM).

4.2 Test Plan

SAIC developed a test plan to describe the experimental setup and measurements to be made with the API lab system modified by AST and housed at their Torrance, Calif., lab. The test plan included a discussion of the performance objectives, metrics, data required and successful criteria goals. The measurements would to be made using the simulated UXO that SAIC designed and fabricated under a previous ESTCP-funded project. Details of the simulated UXO targets are found in Section 4.4. Because the new API 120 generator continued to have issues, AST had to use an older API generator with almost 15 times lower neutron output (~10^6 n/s). With the lower output neutron generator, inspection times on the simulated UXO increased to over an hour each. This further limited the testing to only surface measurements and testing the three largest shells, namely, 81mm, 90mm and 105mm. Each of these shell sizes and their fill types were tested three times for a total of 54 measurements. A test matrix showing the number of measurements for each shell size and fill is shown below in Table 1. The fills include two simulated explosives (TNT, Comp B), three inert materials (POP is plaster of Paris), and empty (no fill material present).

Table 1 Test matrix using lower output API neutron generator.

Target	TNT	Comp B	Concrete	POP	Wax	Empty	Total
81 mm	3	3	3	3	3	3	18
90 mm	3	3	3	3	3	3	18
105 mm	3	3	3	3	3	3	18
Total	9	9	9	9	9	9	54

4.3 Laboratory Test Setup

AST modified their neu-VISION^{T} system so it represented the geometry of a man-portable system that would be used in the field for UXO inspection. The API 120 generator was placed over a box filled with soil and two 3"x3" LaBr detectors were used. One of the LaBr detectors was purchased under SAIC's previous ESTCP project and was provided as GFE. The test setup is shown in Figure 6 at AST's facility in Torrance, Calif. A close-up of the geometry is shown in Figure 7 and includes a 105mm simulated UXO target placed directly below the neutron generator. With this configuration, the timing resolution was approximately 3ns, leading to a spatial resolution of about 15cm. The total field of view was 60º, with an angular resolution of 4º. The total effective volume inspected with this setup was 60cm^3. The neutron output of the older API generator used during testing was about $1x10^6$ neutrons/sec.

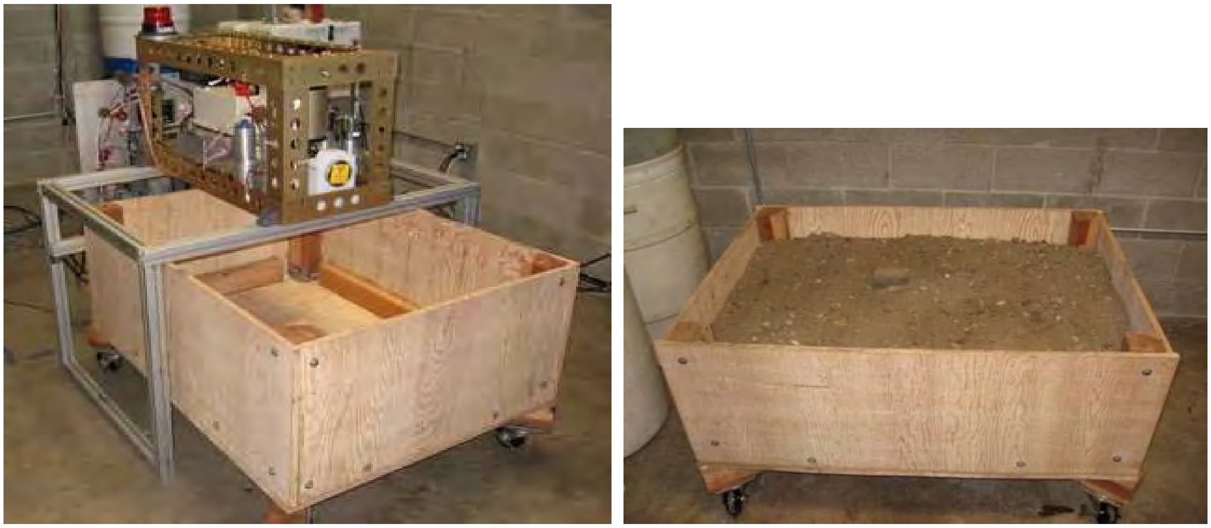

Figure 6 The lab test bed setup showing the neutron generator and detectors supported over the soil-filled box.

Figure 7 Details of the API neutron generator and detector geometry.

4.4 Laboratory Testing

For the lab testing, SAIC provided simulated UXO targets which were fabricated on an earlier ESTP project and represented the shell size (volume and wall thickness) and fill amount for a range of UXO. The complete set of targets represented 30, 60, 81, 90 and 105 mm UXO and the volumes of their fill cavities. Information on the fill amount and casing sizes of a range of ordnance shells was provided on the previous ESTCP project by Environmental Chemical Corporation (ECC) and used in the design of the targets. The targets, shown in Figure 8, were constructed of steel pipes, and steel caps were attached to the ends with epoxy. The sizes of the targets and filler masses are shown in Table 2 (the symbol Φ corresponds to the inner diameter of the steel pipes).

The simulated UXO were filled with the following fills:

- Explosives simulants: CompB, TNT
- Inerts: wax, mortar, POP
- Empty

The compositions of the explosives simulants and how they compare to the compositions of actual explosives are shown in Table 3. The explosives simulants were compressed in the pipes during the fill so that higher densities were achieved (generally the densities were 1.3-1.5 g/cc).

Figure 8 Simulated UXO targets used in lab testing.

Table 2 Container size and filler mass for the UXO test targets.

Fill\Slug	30mm	60mm	81mm	90mm	105mm
Size	Φ0.85", 2.2" long, 0.19" wall	Φ1.7", 3.2" long, 0.19" wall	Φ2.3", 4.9" long, 0.22" wall	Φ3.1", 6.1" long, 0.22" wall	Φ2.7", 13.6" long, 0.50" wall
CompB Simulant	19g	90g	287g	816g	1102g
TNT Simulant	28g	152g	440g	879g	1580g
Mortar	37g	216g	676g	1318g	2690g
POP	30g	172g	530g	1054g	2170g
Wax	14g	90g	281g	532g	1154g
Empty	-	-	-	-	-

Table 3 Composition of the explosives simulants used in the simulated UXO targets.

		C %weight	H %weight	N %weight	O %weight
TNT	Real	37.0	2.2	18.5	42.3
	Simulant	40.1	1.9	19.2	38.9
Comp B	Real	24.7	2.5	30.0	42.8
	Simulant	28.0	2.6	24.4	45.0

During the summer of 2010, the measurements were made using only the 81mm, 90mm, and 105mm shells. They were placed directly below the neutron generator as shown in Figure 7 and were always placed on top of the soil. The data was collected in an event-by-event mode and included the timing information and the energy recorded in the gamma ray detectors. This data was sorted in the analysis to show the gamma ray spectra for individual voxels within the inspected volume.

4.5 Data Analysis

The data analysis was conducted by AST using methods that they developed for the neu-VISION^{T} system. There are two major steps involved in the analysis process for the API data: the base processing and the material analysis processing.

The base processing produces the gamma ray spectra associated with all positions within the inspection volume, as well as one spectrum per detector representing the spectrum of background accidental events. An accidental background is the gamma background produced by natural background sources, an untagged neutron, or a neutron that lost its tagging. For calculating the area for peaks in the spectra, a least squares Gaussian fit is done.

The material analysis processing uses the spectra from the base processing in order to produce estimated relative chemical abundances as well as make a detection decision. Usually the time available for inspection must be kept as low as possible. In practice this means that there are too few counts in any one base voxel to perform an adequate detection analysis. Here, base voxel refers to the finest scale binning in position. It is usually the case that several neighboring base-voxels need to be aggregated into a macro-voxel for adequate statistics in the energy spectrum. The 14 predetermined spectral peaks of interest include the 2220 keV gamma from hydrogen, the 2312 keV gamma from nitrogen (key for identifying explosives), the 4440 keV gamma from carbon, and the 6128 keV gamma from oxygen.

The user selects two special locations in space: (1) the “target region” and (2) the “baseline region.” The regions are selected graphically from images of the inspected volume such as that shown in Figure 9 below. The target region should be selected as the suspected location of a threat material. The “baseline region” should be selected to represent the bulk material that contributes any correlated background. In the case of the data collected on UXO surrogates, the target is the shell’s fill, and the baseline is the soil. These regions define the macro-voxels to be generated. Spectra are compiled for three macro-voxels that here correspond to 1) the user-selected “target region,” 2) the user-selected “baseline region,” and 3) the difference “target minus baseline.” Each of these macro-voxels has an associated “total spectrum” and “accidental spectrum.” The total spectrum is the sum of the spectra of the contributing base voxels, and the accidental spectrum is the spectrum of accidental events expected for the volume defined by the contributing base voxels. The areas within pre-selected peaks, as well as the corresponding uncertainties, are estimated for the spectra for each macro-voxel. The spectra are first adjusted for the expected contribution of accidental events, and a filter is used as part of the peak detection and area estimation. The area data represent the area above the local spectral background and are reported in units of weighted counts.

The spectra associated with these macro-voxels are saved for independent analysis. For each macro-voxel, two different versions of the spectra are saved in different files. The first version is a text file and contains the spectrum after final adjustment for accidental events. The second file is a text file that can be read by standard spectroscopy software.

Next, the relative elemental abundance, a detection statistic (a figure of merit), and an assigned color code are determined for each macro-voxel. The areas from the spectral peaks of interest are converted into estimated relative elemental abundances; expected variances for these abundances are also determined. There are eight elements of interest: C, N, O, Al, Si, S, Cl, and Ca. A threat detection statistic is computed for each macro-voxel. To generate the threat detection statistic, the ratios of various elements are used.

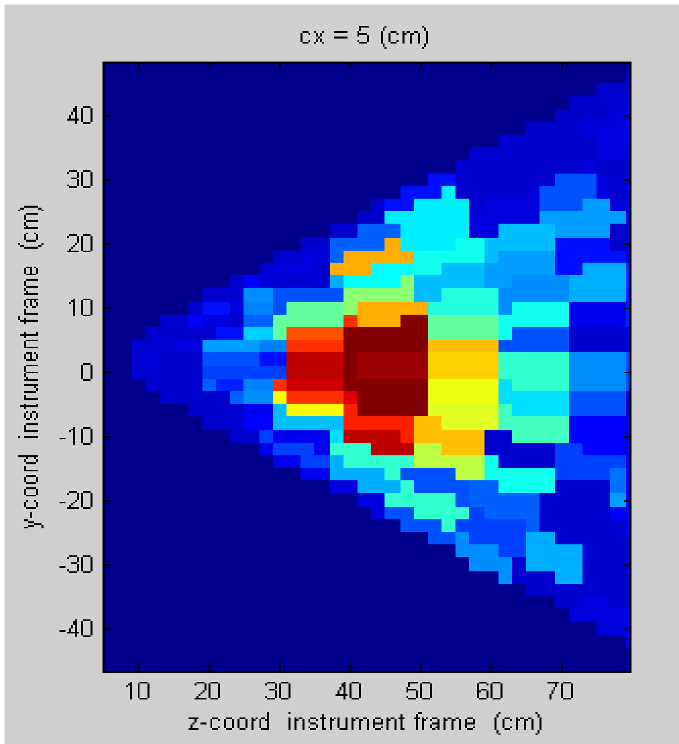

Figure 9 A 2-D slice through voxels in a plane with the neutron source (middle left) and target (red).

The analysis of the UXO fill samples included a relative estimation of the carbon, oxygen, nitrogen, and silicon content for each sample. The carbon to oxygen (C/O) and nitrogen to oxygen (N/O) ratios were then calculated along with their respective uncertainties. Based on the uncertainties for each element, realizations are made changing the value of the elemental abundance to see how many different perturbations can be made that would be indicative of explosive materials. For most explosives detection, heavy emphasis is placed on the presence of nitrogen, so anything with a N/O ratio between 0.4 and 20 as well as a C/O ratio from 0.9 to 5 will send an alarm to the operator. All data are shown in Table 5, including the ratios of N/O and C/O and the identifications made for each target and fill type. Figure 10 illustrates how the data is distributed through the N/O-C/O space.

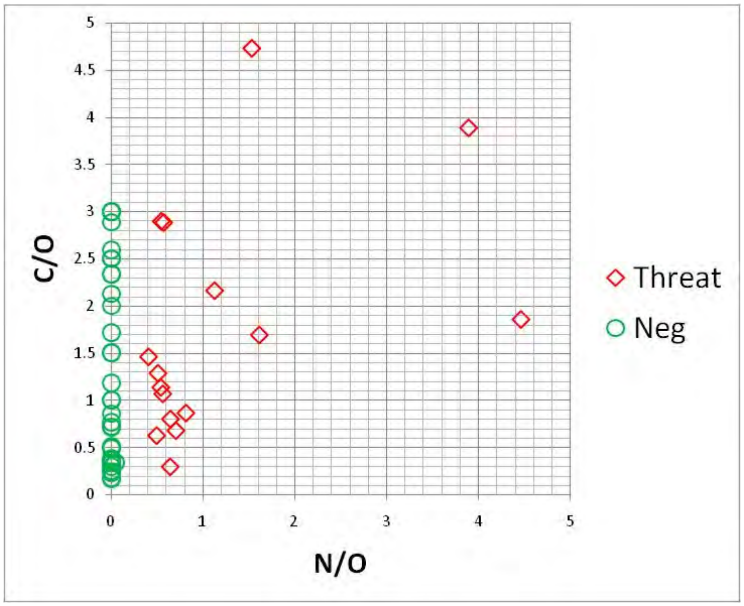

Figure 10 Distribution of N/O and C/O ratios for UXO fill samples.

Based on the 54 simulated UXO samples measured, the system has an accuracy of 93%, with a probability of detection at 83%, and probability of false alarm at 3%. Table 4 shows the data used in the Pdet and Pfa calculations.

Table 4 Calculations for probability of detection and false alarm.

Description	Value
True Positives, TP	15
True Negatives, TN	35
False Positives, FP	1
False Negatives, FN	3
Total Cases, TOT	54
Accuracy = (TP+TN)/TOT	93%
Pdet	83%
Pfa	3%

Table 5 Elemental data results for UXO fill.

ID	Target	Fill	Result	C	N	O	Si	NO	CO
832	81	Comp B	pos	22	21	13	36	1.615385	1.692308
833	81	empty	neg	6	0	6	12	0	1
850	105	Comp B	pos	400	209	185	730	1.12973	2.162162
852	105	empty	neg	15	0	10	44	0	1.5
816	90	empty	neg	42	0	59	159	0	0.711864
817	90	TNT	pos	92	26	63	110	0.412698	1.460317
864	105	Comp B	pos	5	11	17	40	0.647059	0.294118
829	81	Plaster	neg	10	0	13	15	0	0.769231
873	105	Plaster	neg	13	0	11	19	0	1.181818
830	81	Wax	neg	25	0	10	24	0	2.5
874	105	Wax	neg	7	0	3	8	0	2.333333
838	81	TNT	Yellow	5	4	8	14	0.5	0.625
876	90	Comp B	pos	45	18	35	37	0.514286	1.285714
877	90	empty	neg	2	0	2	4	0	1
839	81	Concrete	neg	2	0	12	22	0	0.166667
879	90	TNT	pos	16	13	20	30	0.65	0.8
840	81	Plaster	neg	2	0	6	7	0	0.333333
880	90	Concrete	neg	6	0	20	38	0	0.3
841	81	Wax	neg	114	0	44	117	0	2.590909
882	90	Plaster	neg	4	0	11	12	0	0.363636
883	90	Wax	neg	15	0	10	21	0	1.5
842	90	Comp B	pos	71	23	15	37	1.533333	4.733333
885	81	Comp B	pos	19	18	22	42	0.818182	0.863636
843	90	empty	neg	14	2	41	143	0.04878	0.341463
886	81	empty	neg	1	0	0.001	1	0	1000
844	90	TNT	pos	32	17	30	59	0.566667	1.066667
888	81	TNT	pos	50	24	44	76	0.545455	1.136364
889	81	Concrete	neg	33	0	85	25	0	0.388235
845	90	Concrete	neg	9	0	52	110	0	0.173077
866	105	Empty	neg	1	0	2	3	0	0.5
868	105	TNT	neg	12	0	7	10	0	1.714286
846	90	Plaster	neg	74	0	145	78	0	0.510345
869	105	concrete	neg	28	0	39	96	0	0.717949
890	81	Plaster	neg	2	0	0.001	1	0	2000
847	90	Wax	neg	30	0	12	23	0	2.5
891	81	Wax	neg	2	0	1	2	0	2
799	105	Comp B	pos	70	70	18	105	3.888889	3.888889
800	105	Empty	neg	1	0	4	7	0	0.25
854	105	TNT	neg	87	0	29	63	0	3
801	105	TNT	neg	34	0	0.001	22	0	34000
856	105	Concrete	pos	65	156	35	114	4.457143	1.857143
803	105	Concrete	neg	230	0	108	273	0	2.12963
804	105	plaster	neg	24	0	8	24	0	3
859	105	plaster	neg	78	0	159	309	0	0.490566
806	105	Wax	neg	54	0	18	74	0	3
862	105	Wax	neg	7	0	3	7	0	2.333333
814	90	comp b	pos	75	15	26	48	0.576923	2.884615
824	81	compb	pos	21	22	31	86	0.709677	0.677419
821	90	Concrete	neg	20	0	85	189	0	0.235294
825	81	empty	neg	6	0	7	17	0	0.857143
822	90	plaster	neg	6	0	16	15	0	0.375
827	81	TNT	pos	284	54	98	127	0.55102	2.897959
823	90	wax	neg	112	0	38	104	0	2.947368
828	81	concrete	neg	9	0	58	129	0	0.155172

4.6 Conceptual Design

Based on the experiments conducted with the AST-modified API system, and assuming that a fieldable system would inspect UXO in situ at remediation sites, SAIC and AST developed a conceptual design shown in Figure 11. The system can be powered either externally or using an internal rechargeable battery. The system would break into two pieces for carrying and would weigh approximately 80-90 lbs, similar to that of the PELAN system.

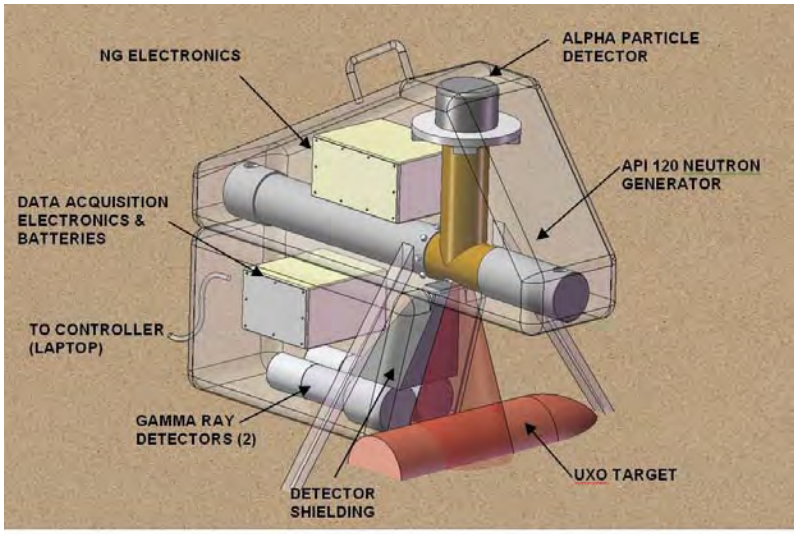

Figure 11 Concept drawing of a man-portable API-based system.

5 CONCLUSIONS AND FUTURE EFFORT

A laboratory model of a man-portable system using the associated particle imaging technology was assembled and tested in the laboratory. The lab model consisted of two 3”x3” $LaBr_3$ detectors and a Thermo API 120 neutron generator operating at a low output of ~10^6 neutrons/sec. Simulated UXO targets constructed on a previous ESTCP project and representing 81mm, 90mm and 105mm sizes were used in the testing. The target fills were Comp B and TNT explosive simulants, mortar, plaster of Paris, wax and empty fills. Measurements were made with the UXO targets placed on the surface of a soil-filled box. Each UXO target was examined three times for a total of 54 measurements.

Based upon the analysis results, we were able to achieve good discrimination between inert and explosive-filled simulated UXO targets, with Pdet=83% and Pfa=3%.

The incorrect identifications are most likely to be due to fluctuations in the neutron output. With a higher output and stable API neutron generator, the performance is expected to improve significantly and inspection times near six minutes are anticipated.

AST and SAIC are supporting the development of a new high-output and stable API generator that is planned to be available in summer 2011. We recommend an effort to evaluate this improved API generator for UXO discrimination and conduct a thorough testing phase of surface and buried, simulated and actual explosives to determine the Pdet and Pfa and verify that inspection times less than 10 minutes can be achieved.

6 REFERENCES

[1] Robert Sullivan. *Improved Analysis Algorithms for UXO Filler Identification*. SERDP Project No. UX-1383, available at www.stormingmedia.us, Feb 2009.
[2] Robert Sullivan. *An Advanced ESTCP PELAN for Surface and Near-surface UXO Discrimination*. ESTCP Project No. MM-200503, available at www.stormingmedia.us, Mar 2009.